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ABSTRACT

Beryllium (Be), a light metal with many desirable material properties, has been used at approximately 20 technical areas at Los Alamos National Laboratory (LANL) since the late 1940s. The purpose of this study was to determine the concentrations, distributions, and trends of Be in surface soils collected at sites within and around the perimeter of the Laboratory. To this end, samples of soil were collected from 17 on-site areas and from 11 perimeter areas from 1992 to 2006. In addition, soil samples were collected around Area G, the Laboratory's principal low-level radioactive waste site, and at the Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility, the Laboratory's principal explosive test site. All samples were compared to regional background. Concentrations of Be measured in soils collected from on-site (n = 153) and perimeter (n = 111) areas over the years ranged from 0.27 to 1.8 µg/g (mean = 0.72 µg/g) and from 0.20 to 1.3 µg/g (mean = 0.65 µg/g), respectively. Most (97%) of the values in soils collected from LANL areas were below the upper-limit regional background concentration (mean plus three standard deviations = 99% confidence level) of 1.2 µg/g and the few values that were above the Regional Statistical Reference Level were far below the New Mexico Environment Department (industrial/occupational) screening level of 2,250 µg/g. The mean Be concentrations in soils collected around Area G and the DARHT facility were 0.57 µg/g and 0.78 µg/g, respectively. There were no significant (α = 0.05) increasing trends in Be concentrations in any of the on-site or perimeter sites over time.

I. INTRODUCTION

Beryllium (Be) (Be metal, Be oxide, copper-Be alloy, Be-steel alloy, Be metal-nonmetal mixtures, or Be salts) was used at 20 different technical areas at Los Alamos National Laboratory (LANL) since 1949 (Stefaniak et al. 2003). Activities included machining, sanding, welding, milling, explosive detonations, and the manufacture of Xray windows to name a few. Although Be has many desirable properties for material construction (it is light and hard and has one of the highest melting points of the light metals), breathing high levels of fine particulate Be dust may trigger an autoimmune response that can result in chronic beryllium disease (LANL 2001, LANL 2002).

Beryllium is naturally found in mineral rocks, coal, volcanic dust, and soil (ATSDR 2002, EPA 2004). The purpose of this paper was to determine the concentrations, distribution, and trends of Be in soil surface samples collected from LANL lands and around the perimeter of LANL and compare these results to what is normally found in the soil at regional background locations. Soil provides an integrating medium (reservoir) that can account for contaminants released to the atmosphere, either directly from air stack emissions or indirectly from re-suspension of on-site contamination.

II. METHODS & MATERIALS

Soil surface samples were collected from relatively level, open, and undisturbed areas at 17 sites within LANL grounds, at 11 perimeter sites surrounding the Laboratory, and at 10 regional locations starting in 1992 (Figure 1). The majority of on-site soil-sampling stations were located close to and downwind, if possible, from major facilities and/or operations at LANL in an effort to assess soils that may have been contaminated as a result of air stack emissions and fugitive dust. In addition, soil surface samples were collected around Area G, the Laboratory's principal low-level radioactive waste site at Technical Area (TA) 54, in 1996 (Fresquez et al. 1997) and 2006 (Fresquez 2006a) and around the Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility, which is the Laboratory's principal explosive test site at TA-15. Pre-operation samples at the DARHT facility were collected from 1996–1999 (Fresquez et al. 2001) and post-operation samples were collected from 2000–2006 (Fresquez 2006b).

Eleven perimeter stations, located within 4 km (2.5 mi) of the Laboratory, were sampled to determine the soil conditions of the inhabited areas to the north (North Mesa, Sportsman's Club, Quemazon Trail, west airport, and east airport) and east of the Laboratory (White Rock, San Ildefonso, Otowi, and Tsankawi/PM-1). Additional samples were collected on the west of Forest Service property (TA-8/GT site) and south

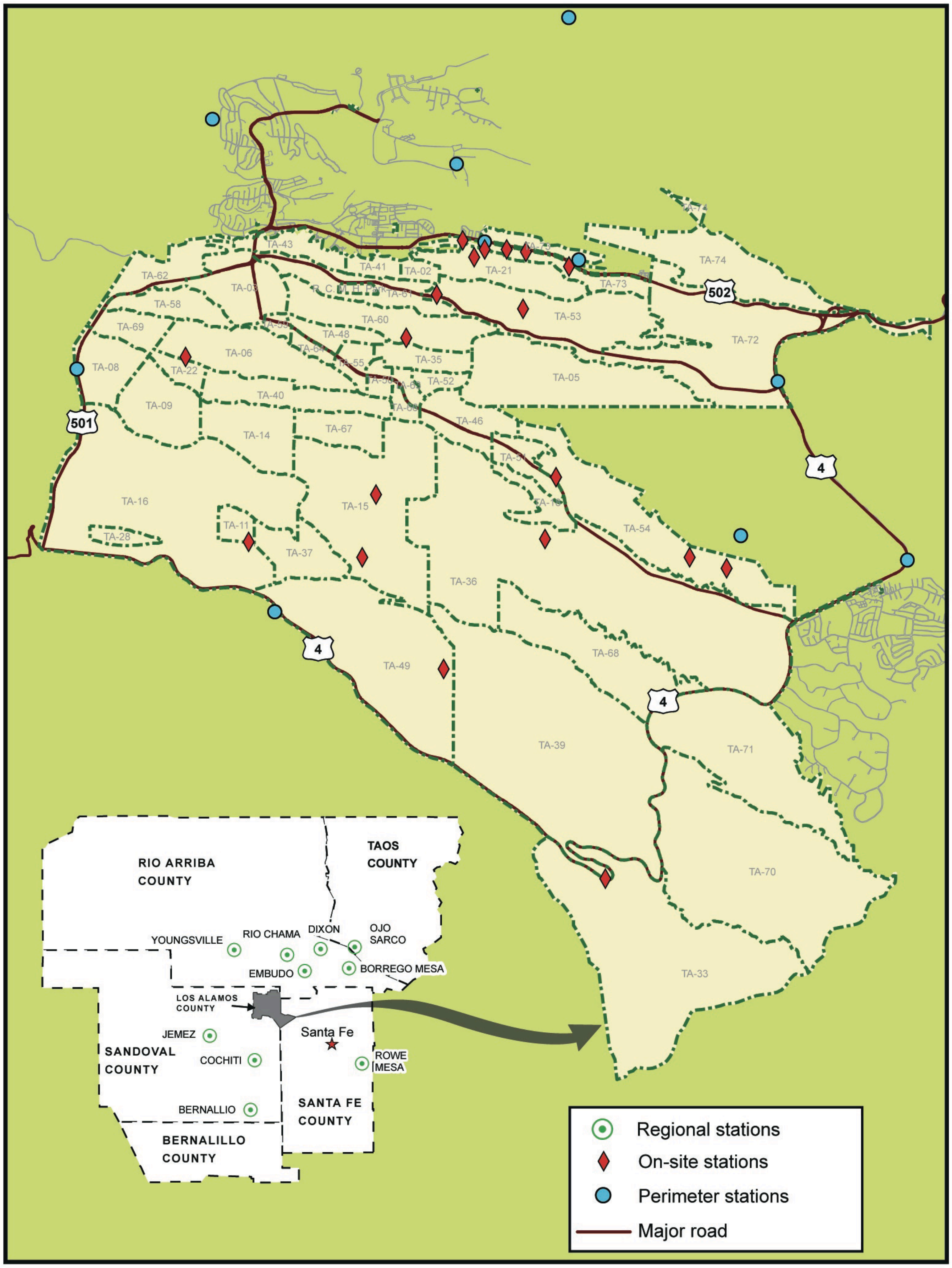

Figure 1. Sampling sites in and around Los Alamos National Laboratory. (Note: The perimeter site at Otowi is off of the map to the right.)

on Bandelier National Monument (BNM) property (near TA-49) to provide comprehensive coverage.

The regional stations were located in all major directions in northern New Mexico surrounding the Laboratory: Rio Chama to the north; Embudo, Ojo Sarco, Dixon, and Santa Cruz Lake (Borrego Mesa) to the northeast; Santa Fe (Rowe Mesa) to the southeast; Cochiti and Bernalillo to the south; Jemez to the southwest; and Youngsville to the northwest. All regional stations are over 15 km (9 mi) from the Laboratory and are beyond the likely range of significant impacts from Laboratory operations; thus, these areas were used to establish "background" levels of Be concentrations.

At most sites, soil surface samples were collected with a stainless steel soil ring 10 cm (4 in.) in diameter pushed 5 cm (2 in.) deep from the center and corners of a square area 10 m (33 ft) per side. The five samples per site were combined and mixed thoroughly in a large Ziploc bag to form a composite sample. Composite samples were then placed in pre-labeled polyethylene bottles that were fitted with chain-of-custody tape. At Area G, samples were collected with a Teflon scoop at the 0- to 6-inch depth. All samples were shipped to Paragon Analytics, Inc., for analysis under full chain-of-custody procedures. The samples were prepared based on SW-846, digested following method 3050B, and analyzed by trace inductively coupled plasma by method 6010B.

To evaluate LANL impacts from Be, if any, the analytical results of soil samples collected from the on-site and perimeter areas are first compared to the Regional Statistical Reference Level (RSRL). The RSRL is the upper-level background concentration based on the mean plus three standard deviations (99% confidence level) from soil data collected from regional locations away from the influence of the Laboratory and represent natural sources. Where the levels exceed the RSRL, they are then compared to the screening levels (SLs) set at the 10^{-5} risk (NMED 2005). The SL for LANL lands (industrial/occupational) is 2,250 µg/g and the SL for perimeter lands (residential) is 156 µg/g. A Mann-Kendall test at the 0.05 probability level was used to evaluate trends over the long term (1992 through 2006) (Gilbert 1987).

III. RESULTS

The concentrations of Be in soil surface materials collected from 19 on-site and 11 perimeter areas from 1992 to 2006 can be found in Table 1. In general, concentrations of Be measured over the years in soils collected from LANL lands (n = 153) ranged from 0.27 to 1.8 µg/g with a mean and standard deviation of 0.72 (0.24) µg/g. Similarly, concentrations of Be in perimeter areas (n = 111) ranged from 0.20 to 1.3 µg/g with a mean and standard deviation of 0.65 (0.25). Most (97%) of the individual values in soils collected from LANL lands were below the RSRL of 1.2 µg/g and the few values (four out of 153) that were higher than background concentrations were far below the industrial/occupational SL of 2,250 µg/g. All but one of the Be values in soils collected from the perimeter sites over the years were below the RSRL. The only value that was above the RSRL was detected near White Rock in 1992 but the difference in concentrations between the two was insignificant (e.g., 1.3 vs 1.2 µg/g) and was far below the residential SL of 156 µg/g. The trend analysis showed that there were no statistically significant (0.05 probability level) upward trends in Be concentrations in any of the on-site LANL areas or perimeter areas over time. One site (Potrillo Drive at TA-36) expressed statistically significant downward trends.

These data are lower in Be concentrations than those reported by Ferenbaugh et al. (1990) in soils that were collected from Sigma Mesa at TA-60 in 1979 (Table 2). Mean Be concentration in soils from Sigma Mesa in 1979 was reported to be 1.9 µg/g (n = 37). One of our sampling sites, "north of TA-50/35 at TA-60," was also located on Sigma Mesa but the mean concentration (0.68 µg/g) was less than one half of the mean Be level detected nearly 20 years ago. With respect to perimeter Be data, the current study results are very similar to that reported in a recent study by Longmire et al. (1995)—they reported a mean Be concentration in perimeter A horizon soils to be at 0.66 µg/g. Also, these data are within Be concentrations reported within the continental United States (Schacklette and Boerngen 1984).

Table 1. Beryllium concentrations (µg/g dry), means (standard deviation), and trends in surface soils collected from LANL, perimeter, and regional (background) locations from 1992 to 2006. (Note: Bold values are greater than the RSRL.)

Location	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Mean	(SD)	Trend [a]
LANL (on-site)																		
TA-16 (S-Site)	1.0	0.72	0.36	0.74	0.83	0.50		1.1	1.0	0.81	0.90	0.78			0.82	0.80	0.21	NST
TA-21 (DP Site)		0.85	0.83	0.74	0.83	0.40		0.83	0.59	0.95	0.43	0.47			0.46	0.67	0.20	NST
Near TA-33	**1.4**	**1.8**	0.62	0.54	0.82	0.50		0.71	0.78	0.65	0.50	0.67			0.65	0.80	0.39	NST
North of TA-50/35 at TA-60	1.2	0.93	0.58	0.53	0.47	0.40		0.70	0.90	0.72	0.48	0.68			0.54	0.68	0.23	NST
TA-51					0.61	0.30		0.89	0.87	0.84	0.61	0.63			0.66	0.68	0.19	NST
West of TA-53					0.82	0.40		0.88	1.0	0.91	0.58	0.71			0.77	0.76	0.19	NST
East of TA-53	1.0	0.79	0.38	0.27	0.45	0.40		1.1	0.57	0.80	0.66	0.89			0.63	0.66	0.26	NST
East TA-54	0.90	0.48	0.37	0.65	0.52	0.30		0.74	0.78	0.76	0.46	0.49			0.50	0.58	0.18	NST
Potrillo Dr. at TA-36	0.97	0.94	0.64	0.93	0.46	0.30		0.66	0.62	0.77	0.48	0.54			0.59	0.66	0.21	SDT
Near Well DT-9 at TA-49	**1.4**	0.78	0.63	0.73	0.87	0.40		0.85	0.81	1.1	0.65	0.75			0.75	0.81	0.25	NST
R-Site Road East at TA-15	0.80	0.96	0.74	0.74	0.87	0.40		1.1	0.97	**1.3**	0.72	0.84			0.73	0.85	0.22	NST
Two Mile Mesa at TA-06	1.0	0.54	0.17	0.47	0.50	0.40		0.87	1.0	0.89	0.51	0.71			0.87	0.66	0.27	NST
TA-73/State Route (SR) 502 (west)															0.46			
TA-73/SR 502															0.48			
TA-73/SR 502															0.87			
TA-73/SR 502															0.67			
TA-73/SR 502 (east)															0.74			
TA-54 (Area G)[b]					0.51										0.63	0.57	0.08	
TA-15 (DARHT)[c]					0.67	0.68	0.67	0.77	0.83	0.75	0.74	0.82	0.94	0.75	0.92	0.78	0.09	NST
Mean (SD) (n = 153)																**0.72**	**0.24**	
Perimeter (off-site)																		
Otowi	0.67	0.41	0.22	0.37	0.44	0.20		0.30	0.58	0.48	0.20	0.33			0.39	0.38	0.15	NST
Across TA-8 (GT Site)	0.50	0.60	0.34	0.40	0.51	0.20		0.87	0.52	0.46	0.47	0.66			0.28	0.48	0.18	NST
Near TA-49 (BNM)	1.2	0.55	0.36	0.63	0.69	0.40		0.87	0.76	0.87	0.54	0.72			0.70	0.69	0.23	NST
East of Airport					0.74	0.30		0.71	0.95	0.74	0.37	0.62			0.62	0.63	0.21	NST
West of Airport					0.62	0.30		1.2	0.96	0.77	0.43	0.47			0.70	0.68	0.30	NST
North Mesa	1.0	0.80	0.56	0.64	0.66	0.30		1.0	0.86	0.62	0.58	0.67			0.71	0.70	0.20	NST
Sportsman's Club	0.72	0.67	0.82	0.56	0.52	0.40		0.90	1.1	0.91	0.63	0.80			0.87	0.74	0.20	NST
Tsankawi/PM-1	1.1	0.74	0.67	0.68	0.91	0.30		0.86	0.92	0.82	0.27	0.67	0.72		0.59	0.71	0.23	NST
White Rock (East)	**1.3**	0.77	0.76	0.79	1.1	0.50		1.1	1.2	1.1	0.82	0.82			0.89	0.93	0.23	NST
San Ildefonso					0.47	0.20		0.63	0.67	0.70	0.42	0.37	0.61		0.69	0.53	0.17	NST
Quemazon Trail															0.48			
Mean (SD) (n = 111)																**0.65**	**0.25**	

Table 1, continued

Location	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Mean	(SD)	Trend
Regional (Background)																		
Embudo	0.70	0.37	0.21	0.44	0.46	0.20		0.62	0.41	0.62	0.38					0.44	0.17	
Cochiti	0.70	0.59	0.46	0.30	0.43	0.10		0.75	0.57	0.48	0.34					0.47	0.19	
Jemez	0.80	0.55	0.37	0.32	0.46	0.20		0.97	0.63	0.74	0.46	0.77			0.63	0.58	0.22	
Rio Chama	0.55	0.32	0.38	0.040	0.32											0.32	0.18	
Borrego Mesa	1.0	0.74	0.52	0.47	0.77							0.41			0.67	0.65	0.21	
Bernalillo	0.70	0.40	0.04	0.63	0.55											0.46	0.26	
Rowe Mesa												0.63			0.85	0.74	0.16	
Youngsville												0.64			0.65	0.65	0.01	
Ojo Sarco															0.74			
Dixon															0.50			
Mean (SD) (n = 55)																**0.52**	**0.21**	
Soil Beryllium Standards																		
RSRL[d]	1.2																	
SL (R)[e]	156																	
SL (I/O)[e]	2,250																	

[a] NST = No Significant Trend, SDT = Significant Downward Trend.
[b]The 1996 result is an average of eight samples and the 2006 result is an average of 21 samples.
[c]Each DARHT value is an average of four measurements.
[d]Regional Statistical Reference Level. This is the upper-limit background concentration (99% confidence level) based on the mean plus three standard deviations (n = 55).
[e]Screening Level (R = residential, I/O = Industrial/occupational) based on 10^{-5} risk from NMED (2005).

Table 2. Concentrations of Be (μg/g) in surface soils reported from other studies within and around LANL lands as compared to other parts of the United States.

Reference	Depth	Range	Mean
LANL			
Ferenbaugh et al. (1990)	0–2 in.	1.1–3.3	1.9
Perimeter			
Longmire et al. (1995)	A Horizon	0.07–1.2	0.66
United States			
Schacklette and Boerngen (1984)		<1–15	0.68

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